

# Audio-Visual Situational Awareness for General Aviation Pilots

Lilly Spirkovska<sup>a</sup> and Suresh K. Lodha<sup>b</sup>

<sup>a</sup>NASA Ames Research Center, M/S 269-3, Moffett Field, CA, USA 94035-1000

<sup>b</sup>Dept. of Computer Science, University of California, Santa Cruz, CA, USA 95064

## ABSTRACT

Weather is one of the major causes of general aviation accidents. One possible cause is that the pilot may not absorb and retain all the weather information she is required to review prior to flight. A second cause is the inadequacy of in-flight weather updates: pilots are limited to verbal updates via aircraft radio contact with a ground-based weather specialist. We propose weather visualization and interaction methods tailored for general aviation pilots to improve understanding of pre-flight weather data and improve in-flight weather updates. Our system, Aviation Weather Environment (AWE), utilizes information visualization techniques, a direct manipulation graphical interface, and a speech-based interface to improve a pilot's situational awareness of relevant weather data. The system design is based on a user study and feedback from pilots.

**Keywords:** Situational awareness, weather visualization, general aviation, speech user interface

## 1. INTRODUCTION

General aviation (GA) flight safety rests on four pillars of situational awareness: position, terrain, traffic, and weather. Loss of weather situational awareness is a main cause of GA accidents and has been attributed as a factor in over 30% of accidents and over 15% of *fatal* accidents.<sup>1</sup> One possible cause is that the pilot may not absorb and retain all the weather information she is required to review prior to flight. Because more data is provided than is applicable to a given flight and the data is presented poorly, it requires much time and cognitive effort to develop a "big picture" view of the weather, especially in an unfamiliar area.

A number of researchers have addressed the poor presentation problem by developing graphical displays of aviation weather for use prior to flight.<sup>2</sup> Most of these displays provide visual representations of data more relevant to commercial airline pilots, as discussed in our earlier work.<sup>3</sup> Data relevant to GA pilots is typically provided only as text or by utilizing a simple color-coding that partitions large geographical areas into areas where aircraft control is possible either by reference to outside cues or strictly by reference to aircraft instruments. In addition to such a categorization, our target audience also needs graphical displays of current and forecast winds aloft, surface winds, cloud layers, and visibility conditions along their route of flight.

A second possible cause of loss of weather situational awareness is the difficulty of tracking weather changes once in flight. In addition to performing the tasks necessary for maintaining awareness of her position, surrounding terrain, and other nearby aircraft, a pilot must obtain in-flight weather updates through voice contact with a ground-based aviation weather specialist. A single weather specialist assists numerous pilots and thus a delay in response may result, especially in deteriorating weather conditions. Once contact is established, the pilot must develop a big picture of current and forecast conditions from an oral description and any notes she takes during the conversation.

Evolving datalink technology aims to improve in-flight updates by transferring weather data (either textual or graphical) to an aircraft via satellite or ground-based communication networks. Due to the current bandwidth limitations, datalink providers are focusing on supplying two subsets of a weather briefing: (1) radar images showing precipitation and (2) textual descriptions of weather conditions and forecasts at selected locations.<sup>4</sup> Although textual descriptions of conditions and forecasts reduces the pilot's effort required to obtain in-flight updates, it still requires much time and cognitive effort to understand the weather situation.

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Further author information: (Send correspondence to L.S.)

L.S.: E-mail: spirkov@email.arc.nasa.gov, Telephone 1 650 604 4234

S.K.L.: E-mail: lodha@cse.ucsc.edu, Telephone 1 831 459 3773

Our system, Aviation Weather Environment (AWE), focuses on improving weather situational awareness by general aviation pilots both on the ground and in flight by providing graphical displays of textual weather data. Additionally, to reduce time spent looking inside the cockpit ("head-down time") accessing in-flight weather updates, AWE provides speech-based interaction. Our graphical representations were preferred by pilots when compared with seven representations used by alternate systems.<sup>3</sup> Moreover, evaluation by pilots<sup>5</sup> showed that AWE enables pilots to answer pre-flight route-planning relevant questions 2.5 times more quickly when compared to conventional pre-flight weather reports. When compared to conventional in-flight updates, it decreased the workload required to plan for a diversion by 5.5 times while doubling the likelihood of reacting to simulated aircraft anomalies. In this paper, we describe enhancements in information displays developed due to feedback from the pilot evaluators including weather trend information, display of multiple forecast elements, and multiple winds aloft. We also present a speech interaction functionality that significantly reduces in-flight head-down time. We begin with a brief summary of our previous work on AWE in Sec. 2 and conclude with our future plans.

## 2. BACKGROUND

Pilots can get official aviation weather briefings either via telephone contact with an aviation weather specialist or via computer contact with DUATs,<sup>6</sup> Direct User Access Terminals. Both methods require the pilot to decipher verbal or textual data to develop a picture of the weather situation. In this section, we briefly describe DUATs – the input to our system. We then provide an overview of emerging technology for in-flight digital data transfer that can be utilized to transmit updates of a portion of a DUATs briefing. We conclude with graphical representations designed to decrease the cognitive resources required to develop a weather picture. We provide details of these representations in order to explain several improvements incorporated to increase the situational awareness of pilots.

### 2.1. DUATs

DUATs, Direct User Access Terminal system, is the official digital source of weather information for pilots. A DUATs weather briefing provides information and forecasts on the position of fronts and pressure systems; wind conditions at airports and forecasts for winds at various altitudes to 39000 feet; current and forecast cloud layers; weather (such as rain); visibility conditions; warnings about meteorological conditions such as thunderstorms, turbulence, mountain obscuration, widespread low visibility conditions, and icing conditions; notices about such things as airport closures, unlighted obstructions, and out of service equipment; and reports from other pilots about actual conditions encountered.

AWE considers the visualization of three elements of a DUATs report: current weather (METARs), forecast weather (TAFs), and winds aloft forecasts. METARs provide specific meteorological observations about individual airports including surface wind velocity, visibility, any obstructions to visibility (such as fog, haze, or rain), altitude of clouds and amount of sky covered by each cloud layer, temperature, dew point, barometric pressure (also called *altimeter setting*), and clarifying remarks. TAFs provide a forecast for conditions at the airport for a 24-hour period separated into individual elements describing conditions forecast for a portion of the period. Each element specifies the time range for the applicability of that portion; a forecast for surface wind velocity; visibility and obstructions to visibility; and altitude and amount of sky coverage for cloud layers. The effective time period for elements can overlap and probabilities can be associated with forecast conditions. Winds aloft reports forecast wind velocity and temperature at various altitudes from 3,000 feet to 39,000 feet, generally at 3000 foot increments. Reports are provided for widely-spaced airports. Wind velocity and temperature for intermediate locations and intermediate altitudes must be interpolated from the given values.

### 2.2. Datalink

As of February 2002, pilots are able to receive up-to-date weather information while in flight. The Federal Aviation Administration (FAA) provides the radio frequencies for broadcasting weather,<sup>7</sup> and industry<sup>8,9</sup> provides the ground infrastructure and avionics required to transmit and receive the data. Ground station networks continuously broadcast selected weather products, including METARs and TAFs. Broadcasts are one-way (ground to air) and most products are broadcast at least once every five minutes.

In addition to the FAA sanctioned transmission approach, two other approaches are available: satellites and the ground-based cellular telephone network.<sup>10</sup> The satellite transmission method uses a low-Earth-orbit data

communication satellite and a private weather data provider.<sup>11</sup> This approach provides two-way messaging to pilots: a pilot issues a request for information using a cockpit-mounted keyboard, and then waits for the system to fill the order and broadcast text and graphical weather products back to the airplane. The other approach relies on the existing ground-based cellular telephone network.<sup>12</sup> Special horizontally polarized antennas are co-located at 150 cell sites. The pilot uses a specialized cellular telephone to request and receive weather products. With either approach, the data can be displayed on a cockpit-mounted display, a portable personal computer, or a personal digital assistant (PDA).

### 2.3. Surface Conditions Graphical Representations

AWE provides three representations of METAR and TAF data. Each representation serves a different purpose. The *triangular icon* representation provides the pilot with a quick-glance overview of the major elements. The *symbolic visual* representation provides her with an easy to interpret display of critical elements along with most of the other elements of a report. Finally, the *textual* representation provides precise values for all elements of a report. All three representations utilize color-coding to highlight adverse conditions.

**Triangular Icon Representation:** The triangular icon representation provides a general overview of weather conditions. It presents the four primary elements that affect a pilot's "go/no-go" decision: wind conditions, visibility, cloud altitude, and temperature / dew point spread. Each element is depicted as a color-coded triangle. The four triangles are grouped into a large triangle and shown alongside the applicable airport. Each subtriangle is color-coded white, yellow, or red to depict good, marginal, and adverse conditions respectively. Both METARs and TAFs can be displayed using the triangular icon representation. However, since TAFs do not provide temperature or dew point, the subtriangle representing the spread is always gray.



**Figure 1.** Area TAF display using triangular warning icons. The top, lower left, lower right, and the middle subtriangles represent winds, visibility, clouds and temperature/ dew point spread conditions respectively. Red, yellow, and white colors indicate alert, caution and normal conditions respectively. Grey color indicates that the information is not available.

**Symbolic Visual Representation:** The symbolic visual representation, shown in Fig. 3, provides more details than the triangular icons. The symbols encode surface wind speed and direction, cloud conditions at different altitudes, and visibility conditions.

**Surface Winds:** The wind speed and direction are displayed within the top square. The direction is encoded by the direction of an arrow such that the compass is overlaid with North at the top. The wind speed is encoded by the width of the arrow, with thicker arrows representing stronger winds. Thus, the amount of white within the square corresponds to the strength of the wind and provides the pilot a quick clue about wind conditions. Further, for additional aid to the pilot in detecting adverse conditions, the border of the wind square is color-coded using the same color-coding values used in the triangular icons.

**Clouds:** Cloud altitudes are shown on a vertical rectangle that represents the sky from 0 to 12,000 feet. The maximum cloud height was chosen for consistency with the height detectable by automated weather observation systems. The cloud rectangle is pseudo-colored to represent the cloud layers.<sup>13,14</sup> As suggested by Bertin<sup>15</sup> and Tufte,<sup>16</sup> we chose a gray scale to represent the five possible cloud amounts so pilots do not need to remember a color key. White represents a clear sky and progressively darker grays represent thicker coverage with very dark gray representing an overcast sky. Ceilings (defined as broken or overcast layers) are thus quickly recognized by scanning for darker grays.

**Visibility:** The border of the cloud rectangle is color-coded to instantly show whether the visibility conditions are poor, marginal, or good using the same color-coding values used in the triangular icons. The actual visibility value and any obstructions to visibility are displayed as text below the symbol.

**Textual Representation:** The pilot is able to view all the information related to a METAR/TAF textually. A textual display of METAR information is shown in Fig. 2. To make the task of recognizing crosswind conditions quicker, the surface wind direction is represented graphically as well as textually. The remaining elements are presented only textually. The textual displays are supplemented with color-coded borders to warn the pilot of possible adverse visibility conditions, using the same thresholds as for the triangular icon representation.



**Figure 2.** Close-up view of a textual representation of a METAR. The wind direction is shown by the arrow. The wind direction and wind speed are also shown by the text in the upper right corner. In this case, the wind is coming from 60 degrees at 3 knots. The visibility is 5 miles with 'BR' or mist. Cloud layers are given as a few clouds at 1500 feet and scattered clouds at 5000 feet. Finally the temperature and dew point are both 4 degrees and the barometric pressure is 30.21 inHg. The colored rectangle (yellow) represents marginal visual flight conditions. It would be colored red for poor visibility conditions or gray for good visibility.

## 2.4. Winds Aloft Graphical Representation

AWE displays only the velocity element of winds aloft reports for a pilot-specified altitude. For each airport along the pilot's route of flight, AWE computes the wind velocity forecast for the chosen altitude by interpolating between the two nearest reporting airports and the two nearest reportable altitudes. The computed wind velocity is displayed using simple arrows: the wind arrow is rotated to encode the direction and the wind speed is shown as text inside the arrow. By manipulating an altitude selection slider, the pilot can evaluate potential cruising altitudes interactively.

# 3. INFORMATION DISPLAYS

Through interviews and questionnaires, we determined that pilots preferred the above graphical representations over seven representations from four competitive systems.<sup>3</sup> The pilots of our user study suggested three additional features: display of trend information, display of multiple forecast elements, and simultaneous display of winds aloft for multiple altitudes. The following subsections describe these new pilot-inspired displays.

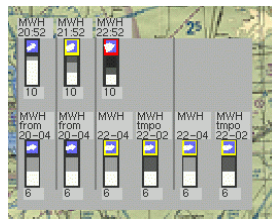
## 3.1. Trend Information Display

DUATs provides only the METAR reports for the current hour (or the most recent previous one, if the current hour report is not available). Hence, our original implementation of AWE provided a graphical display of these most recent METAR reports. The user study revealed that the pilots wanted the ability to look back at previous reports in order to see developing trends in the weather and to discern how accurately actual conditions were predicted by the forecasts.

In order to address this feedback, we developed a two-layer weather trend display. The bottom layer displays the forecast applicable at time  $t - 2$  hours,  $t - 1$  hour, current time ( $t$ ), and  $t + 1$  hour. The top layer presents the actual conditions observed at time  $t - 2$ ,  $t - 1$ , and  $t$  and is aligned with the same time stamps as the bottom

layer. An example trend display using the symbolic format is shown in Fig. 3. If desired, the pilot can also display trends using the triangular icon representation.

The top layer of information associated with a given airport provides information on how the weather actually changed and enables the pilot to visually detect developing trends in wind conditions, clouds, or visibility. The comparison of the corresponding time periods of the two layers provides information on the accuracy of the forecasts. Depending on whether the actual conditions support or refute the forecasts, the pilot can determine the likelihood that the weather forecast for the next hour was accurately predicted. Although statistical approaches can be used to derive measures of uncertainty of predictions, most pilots are more comfortable and trusting of raw data rather than interpretations of the raw data by algorithms they may not understand. It is also very easy for a pilot to perform a visual pattern comparison. Nevertheless, if algorithms are designed to derive prediction uncertainties that gain the trust of pilots, such measures can be shown within AWE either augmenting or replacing the trend display.



**Figure 3.** Display of trend information for an airport. The top layer displays the winds, cloud, and visibility as measured; the bottom layer displays the winds, cloud, and visibility as predicted. Each layer shows the current hour (in the third slot), the previous hour (second slot), two hours prior (first slot), and the forecast for the next hour (fourth slot). Correlation or discrepancy between the two layers allows pilots to determine how reliable the prediction for the next hour is likely to be. In this example, we see that the winds are much stronger and the clouds are lower and thicker earlier than forecast.

By studying Fig. 3, a pilot can see the discrepancies between the actual readings and the predictions. Observe that the surface winds are predicted to be moderate consistently while the actual readings show the wind speed increasing prematurely and more severely than forecast, predicted and actual visibility conditions correlate well, and cloud layers are lower and thicker with conditions deteriorating earlier than forecast.

There are certainly other representation possibilities for weather trend information. For example, the actual and predicted conditions for the three elements can be displayed using a continuous graph-based representation. While such a representation may be more useful for longer time periods because it may occupy less screen area, it may be less suitable due to the effort of determining the location of the current time period on the graph. A further advantage of AWE's trend display is that it does not require much additional training because it builds on familiar representations.

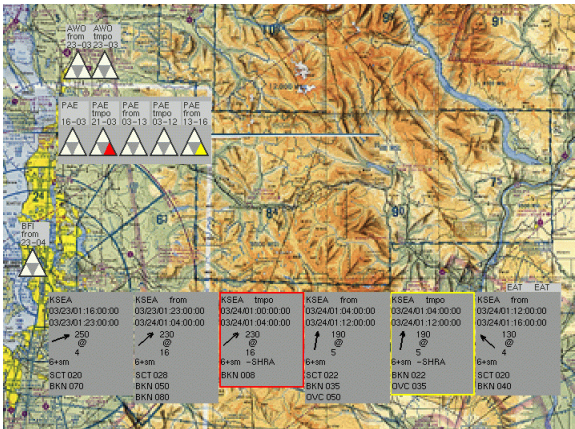
### 3.2. Multiple Forecast Element Display

A DUATs TAF report contains forecasts for conditions at the airport over a 24-hour period. Each significant change in expected conditions is encoded as an individual element preceded by the time of expected change. In the original implementation, AWE automatically selects the applicable forecast elements for the destination and en-route airports based on the pilot-specified departure time and the AWE-computed estimated time of arrival, ETA, at each airport. This reduces the pilot's workload by eliminating the need to determine these ETAs and then determine which forecast element applies. Though the user study pilots found this feature useful, they also wanted the option of viewing the entire 24-hour forecast because the partitioning of the period helps in estimating the certainty of the forecast for a given ETA. That is, if the weather is predicted to change 30 minutes after the ETA, it may be prudent to have a backup plan in case the change occurs earlier. Similarly if the ETA is 20 minutes after fog is forecast to clear, it may be prudent to plan for an alternate destination in case it does not clear on schedule.

We have incorporated this suggestion and provide the pilot the option to display the predicted weather for all time periods of a TAF. Rather than having AWE select the appropriate forecast for the ETA, the entire series of forecast elements is displayed. The time labels allow the pilot to determine not only *if* a change is forecast,

but also *when*. She can choose any one of the three visual representations – textual with color-coded borders, triangular icon, or symbolic – to visualize multiple forecasts at several airports simultaneously.

Figure 4 shows an example of a multiple TAF element display. Airports AWO (Arlington, WA) and BFI (Boeing Field, WA) are shown using the standard forecast conditions display. BFI shows the single TAF element that is applicable for the selected departure time, whereas AWO shows two elements applicable for that time. Airports PAE (Paine Field, WA) and SEA (Seattle-Tacoma International) are shown using the multiple TAF element display. It is evident from the color-coding of the icon representation used by PAE that the ceiling will temporarily be below 1000 feet between 21:00Z and 03:00Z. It is then forecast to lift above 3000', until 13:00Z when it will again drop below 3000' but remain above 1000'. The textual representation for SEA provides further details about the situation: the ceiling is predicted at 800 feet from 00:00Z to 04:00Z, lift to 3500' after 04:00Z with a temporary marginal ceiling (broken clouds at 2200') from 04:00Z to 12:00Z.



**Figure 4.** TAFs for four airports. AWO and BFI show just the forecast elements applicable to the AWE-computed estimated time of arrival. PAE and SEA show all the elements associated with a particular airport for the entire 24-hour period. The multiple forecast element display can be used to determine when and what type of changes are expected during the forecast period.

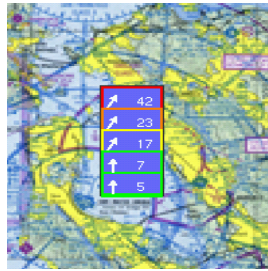
### 3.3. Multiple Altitude Winds Aloft Display

Using the single altitude display to formulate a big picture of the winds aloft for a range of altitudes, the pilot needs to watch multiple arrows as she moves the slider and also needs to remember wind velocity for previous altitudes. The multiple altitude representation provides simultaneous display of wind velocity at all altitudes relevant to our target audience to allow for a quick visual evaluation. We show only the reportable altitudes (3000, 6000, 9000, 12,000, and 18,000 feet) – the pilot must interpolate manually for intermediate altitudes.

In the simultaneous multiple altitude representation, shown in Fig. 5, the wind velocity for each of the five altitudes is shown in its own color-coded rectangle. The direction is shown by an arrow and the speed is given by the adjacent text. The color of the rectangle's border is determined by the wind speed and a modified stop-light scheme with green for calm winds (< 10 kts), yellow for moderate winds (< 20 kts), orange for stronger winds (< 30 kts), and red for very strong winds (> 30 kts). The five individual altitude rectangles are stacked vertically, with 3000 feet at the bottom. The altitude associated with each rectangle is not shown in order to decrease clutter. Because the altitudes follow standard DUATs reports, they are typically already internalized by pilots. A *help screen* is available for a reminder.

## 4. SPEECH-BASED USER INTERFACE

The human visual channel has the highest bandwidth, outperforming the others by a large margin. In certain situations, such as in mobile, hands-busy, eyes-busy environments, the visual channel is overwhelmed by all the tasks it must attend to. Experimental evidence indicates that if a user is performing multiple tasks, performance improves if those tasks can be managed over independent input/output channels, or modalities.<sup>17</sup> Consequently, AWE provides speech input and output to complement the pilot's access to weather data, especially during flight.



**Figure 5.** Winds aloft forecast shown for multiple altitudes simultaneously. The individual altitude rectangles are color-coded using a modified stop-light scheme to quickly inform the pilot of wind conditions.

Using speech, the pilot can extract information without having to devote much visual attention to the task, under different ambient lighting conditions from direct sunlight to total darkness, while she is scanning for traffic or scanning flight instruments, and while she is busy controlling the airplane.

Speech has a number of advantages. It has low panel real-estate needs – small GA cockpits do not allow for much additional input-output paraphernalia. Speech as an input modality is quicker than either typing or writing – a person can speak several hundred words per minute, an excellent typist can produce 80-100 wpm, and one can hand write at less than half the typing rate.

Speech also has disadvantages. Listening is slower than reading – people easily read 350-500 wpm, whereas typical speaking rates are 175-225 wpm. Increasing speech rate requires considerable attention by the listener so it is typically not recommended. Speech is also temporal – once spoken, the message is gone. Speech output is serial and “bulky” – only one word is spoken at a time versus a menu where many choices are presented simultaneously. This increases the load on the listener. Further, synthesized output tends to sound unnatural and can be misunderstood until the listener becomes accustomed to its accent. Finally, the technology is still immature; it works best with easily distinguishable vocabularies and limited grammars.

The advantages outweigh the disadvantages in the GA domain for a number of reasons. First, the official language for aviation is English, even in non-English speaking countries; non-English speakers (pilots, air traffic controllers, and flight service specialists) must learn enough English to transfer necessary information. Second, due to radio frequency congestion, non-English speaking air traffic controllers and pilots, and the possibility of misunderstanding, pilots are trained for and accustomed to predefined, limited vocabularies and terse grammars. Pilots are also accustomed to simplex communication using a headset or hand-held microphone. Lastly, they are already accustomed to receiving weather data through a speech synthesizer.

In the following sections, we describe AWE’s speech input and output individually.

**Speech Input:** AWE does not implement a natural language understanding system. Other experiments have revealed that such systems confuse the user into believing he can talk about anything, not just the narrow scope implemented. We also chose not to implement a dialog tree<sup>18</sup> where a user is prompted at each step until predetermined slots are filled. Dialog trees are useful in situations where the user will not get any pre-use training, such as telephone bank tellers. But they do not mimic communications typically found in GA and can be frustrating to use. Command and control interfaces better mimic other GA communications; pilots, after some initial training, should find them more pleasant to use.

Since pilots are accustomed to using standard phraseology, AWE implements a specialized vocabulary and grammar, and uses IBM’s ViaVoice for speech recognition. A grammar supports substitution and repetition, allowing for a more flexible and more complex interaction. As defined by IBM, a grammar is a “structured collection of words and phrases bound together by rules that define the set of all utterances that can be recognized by the speech recognition engine at a given point in time,” with an utterance defined as a “stream of speech that represents a complete command.” Because grammars constrain the valid set of words to be considered, recognition accuracy is expected to be higher than with dynamic vocabularies. Since a grammar supports substitutions, it can be designed to allow the user to phrase commands in many different ways. A larger grammar is more tolerant of word and sentence variation; however, like in natural language systems, it also leads to greater expectations from the user: he may think he can say just about anything. Or he may forget what to say. We designed

AWE's grammar to be flexible enough to support different phraseology, yet constrained enough to help the pilot remember what to say and to optimize recognition accuracy.

IBM ViaVoice allows the simultaneous use of a dynamic vocabulary and a grammar. AWE defines only a simple vocabulary: "quit" and "goodbye." All other directives that can be issued to the recognition engine are encoded by the grammar. It is challenging to design a grammar that provides the pilot with sufficient expressive power to ask for what she needs, but remains limited enough to get fast and accurate recognition. The grammar is written in the Speech Recognition Control Language (SRCL), which is basically a BNF (Backus-Naur form) grammar adapted to speech recognition. Like a BNF grammar, it has a set of production rules with non-terminals, terminals, and some predefined terminals that allow the developer to specify optional words or repeated words.

The AWE grammar is constructed to constrain the pilot to request current airport conditions (METARs), airport forecasts (TAFs), and winds aloft forecasts; to set program parameters aurally; and to request some supplementary data. To decrease the likelihood of recognition errors, AWE offers seven distinct sounding basic actions: *show*, *hide*, *say*, *set*, *clear*, *highlight*, and *register*. *Highlight* tells AWE to draw a box around an airport. This helps a pilot in locating airports on the chart. *Set*, *clear*, and *register* enable the pilot to verbally manipulate display and other program options. Finally, *show*, *hide*, and *say* work on METARs, TAFs, and winds aloft. They also provide additional, potentially helpful, data. Some examples of directives for accessing winds aloft include *show area winds aloft at five thousand five hundred*, or *show route winds aloft all altitudes*, or just *show winds aloft*. AWE uses the values for *display extent* and *cruising altitude* shown via the graphical user interface (GUI) to fill unspecified parameter slots. Winds aloft will be displayed as described in Sec. 2.4 or Sec. 3.3. She can also *hide route winds aloft*. To get a verbal reply, she can state *say winds aloft for S F O at five thousand five hundred*. Or she can have AWE pre-process the data and answer *say best altitude for northwest-bound winds aloft* or *say best winds aloft for three four zero degrees*.

METAR requests similarly rely on the *show*, *hide*, and *say* verbs. For example, the pilot can state *show route metar as symbol*, *show area current weather*, or just *show metars*. Any missing parameters are set to what is displayed on the GUI. She can also bypass keyboard commands and ask for a textual representation aurally: *show Palo Alto weather as text*. To go back to the previous representation, she can state *hide Palo Alto text* or to clear all METARs *hide metars*. During flight, it is useful to ask for specific data and get a voice response. For instance, the pilot can ask *say winds at Hayward* or *say ceiling at Santa Rosa*. She can also simulate listening to an automatic weather report (known as ATIS or AWOS) and state *say metar for Palo Alto* to hear the complete report using the familiar ATIS format. When determining whether takeoff is possible, she may ask *say density altitude for Lake Tahoe*. Or if the weather has not cleared before arriving at her destination and she would like to divert rather than hold, she can ask *say nearest VFR* or *say closest clear weather*. Or she can ask AWE to translate Celsius values to the more familiar Fahrenheit: *say fifteen Celsius as Fahrenheit* or even *say temperature at San Jose as Fahrenheit*.

Forecast weather requests utilize a similar construction, changing *taf* or *forecast weather* for *metar* and *current weather*, and adding slots for ETA. Hence, the pilot can state *show area tafs as symbols at sixteen hundred zulu*, *show forecast as icons*, or *show tafs*. Similarly, she can bypass keyboard commands and state *show Oakland taf as text*, *show Stockton complete forecast as icons*, or *show Monterey complete forecast as text*. To see a trend display, she could state *show San Francisco trend as symbols*.

*Hide* commands are parallel to METAR *hide* commands. *Say* commands are also parallel. For example, *say winds at Salinas at thirteen thirty zulu*, *say ceiling at Sacramento at eight hundred*, or *say pattern altitude for Modesto*. Similar to asking about the nearest VFR, a pilot may want to know how close she is to instrument conditions. She can ask *say closest I F R* and then, if she is unfamiliar with the location of that airport, e.g. Madera, *say highlight Madera*.

Notice that the grammar is fairly constrained and generates terse phrases. Friendly or chatty phrases wear thin, especially when the pilot is busy with other tasks, and politeness is unnecessary in communications with computers. AWE may still fail to recognize a phrase. In this case, it will respond via the GUI with *Say again* followed by the words it understood. The pilot must then repeat the phrase or rephrase to use acceptable phraseology.

**Speech Output:** *Say* commands trigger AWE to provide a voice response. Like for speech recognition, AWE uses IBM ViaVoice for speech synthesis. Responses mimic phraseology already in use between pilots and controllers. For example, controllers ask pilots *say intentions* and pilots on final approach for landing ask *say*



*winds*. If either did not understand a request, *say again* is the typical response. We chose an implicit confirmation strategy for aural feedback. AWE does not explicitly ask the pilot "Did you say ...?" and then wait for a *yes* or *no* before answering. Rather it provides a succinct answer to a query but also provides enough context so the pilot knows the request was understood correctly. If she detects that an incorrect question is being answered, she would reissue the query, just as she would if speaking to a ground-based weather specialist who misunderstands a query issued over the aircraft radio. We feel this is justified because AWE provides answers to queries. Therefore, a recognition error results in a delay in the pilot getting the information, but is otherwise harmless.

Just like directives, answers are terse, not friendly or chatty. Some example output sentences, answering questions posed in the previous section, are: *Wind at Hayward is three five zero at fifteen; Ceiling at Santa Rosa is fifteen hundred feet; Palo Alto airport, wind 3 5 0 at 15, visibility 1 0, scattered at two thousand five hundred, broken at twenty thousand, temperature twenty, dew point ten, altimeter three zero zero seven.*

## 5. SUMMARY AND FUTURE WORK

AWE has been tailor designed to suit the needs of general aviation pilots. It focuses on the gaps found in other aviation weather visualization systems by providing graphical representations of airport-specific current weather observations, airport area forecasts, and winds aloft reports. Evaluation by pilots resulted in useful feedback about the usability of AWE and led to the additional representations and speech-based user interface described in this paper.

Our next step is the development of an interface agent to take the initiative in providing information it determines may be of use to the pilot in order to further decrease her workload. For instance, when new weather updates are received, AWE can automatically look for inconsistencies between the forecasts and the evolving conditions. If it detects any unexpected conditions, it can spontaneously warn the pilot. Of course, all the data will also be available to the pilot for her own exploration.

AWE already provides useful functionality to help a pilot maintain an awareness of the weather situation. With planned future functionality, she will be able to maintain weather situational awareness with further reduced workload.

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